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HOW RISKY IS INTERCEPTNG FARM RUN-OFF? ASSESSING THE RISK OF PROPOSED STORM WATER DETAINMENT BUND PS120© SITES ON NZ FARMS.

John Paterson[1] and Natalie North[2]

[1] Phosphorus Mitigation Project, PO Box 1038, Rotorua 3040, New Zealand
[2] Landpro, PO Box 302, Cromwell 9342, New Zealand
Email: John.PatersonPMP@gmail.com

Abstract

Ten years of applied research on intercepting storm water run-off has confirmed that the Detainment Bund PS120© (DB) is a suitable mitigation tool for reducing phosphorus and sediment losses from farming operations. Serving catchments from less than 10 ha to over 40 ha, and constructed on pasture with free draining soil types, DBs can reduce contaminant losses in storm water run-off by ~ 57.5 % without compromising pasture quality.

With the wider implementation of DBs it has become clear that the benefits, costs, and risks potentially associated with DBs has not yet been specifically considered or recognised by regulatory authorities. Consequently, DBs have fallen into the same regulatory category as permanent dam constructions, automatically being treated as a high-risk undertaking requiring a high level of engineering oversight and its consequent cost. This high risk / high-cost approach is severely inhibiting the uptake of DBs and impeding the achievement of water quality goals. Due to the nature of their design and location on first and second-order Strahler stream flow paths, the risks and downstream consequences of DB failure are generally inherently lower than the risks and consequences commonly associated with dam wall failure.

This paper defines the key risk elements of prospective DB sites which are categorised, scored, and ranked using a prototype tool that PMP Inc. has recently developed: **The Detainment Bund Risk Assessment Algorithm (DBRAA)**. The method gauges farm site risks through preliminary DB site assessment mainly by using attributes derived from landscape GIS data with high resolution LiDAR data. The algorithm processes attributes scored for ten elements of risk that collectively contribute to the potential for possible DB failure. The elements of risk are: DB wall height and ponding volume; catchment size; upstream and downstream slope; soil drainage, local geomorphology; sub-soil construction materials, distance to boundary and proximity of vulnerable infrastructure in the downstream flow path.

For each risk grade, an appropriate level of professional engineering design and oversight is assigned. This means that low risk sites will have relatively low-cost design and oversight requirements while high risk sites will have an appropriately higher level of engineer oversight. The desired outcome is that DBs will eventually be appropriately regulated according to measurable risk of failure parameters, and costs of design and oversight will be appropriately matched to the actual risk of failure. This will reduce barriers to farmer uptake and constructing water quality mitigating DBs in low-risk sites on farms will be both safe and have less cost impediment.

Introduction – Pastoral contaminant loss pathways

There are four main contaminants commonly leaving pastoral farming operations that can have profound effects on the quality of downstream public water bodies. These key contaminants are nitrogen, phosphorus, sediment, and pathogens. Individual farm owners and managers are increasingly taking action to minimise contaminant losses using existing mitigation tools. Farmer governed collaborations are trialling new mitigation methods and, in some cases, leading applied research on innovative approaches e.g., Phosphorus Mitigation Project Inc. (Paterson, 2019a). Preventing mobilisation of contaminants in the first place is the most economical and most effective priority action that farmers can initiate (McDowell, 2010). Adoption of farm plans that schedule 'good practice' for improving environmental sustainability is becoming standard practice, albeit aided now with regulatory push from Governments (NPS, 2020). Coupling preventative actions with an ethic of "continuous improvement" (Carruthers, 2011), demonstrable via a farm plan, will minimise gross loss of contaminants from farms. However, even with the best application of 'good practice', contaminant losses from highly productive farm systems will persist to some extent through the natural drainage **pathways** of the farm landscape.

The two main loss **pathways** of New Zealand's four key agricultural contaminants are by either; **seasonal loss via infiltration** (leaching to aquifers) or **episodic loss via surface runoff events**.

Losses of nitrate nitrogen occur whenever rainfall infiltrates and the soil moisture conditions enable leaching to progress and deliver nitrate to groundwater. In the Oturoa Road example (Figure 1), leaching is likely to progress from mid-May to the end of October or approximately 45 % of the year but then take ≈75 years (Morgenstern, 2014) to reach the destination waterbody (Table 1).

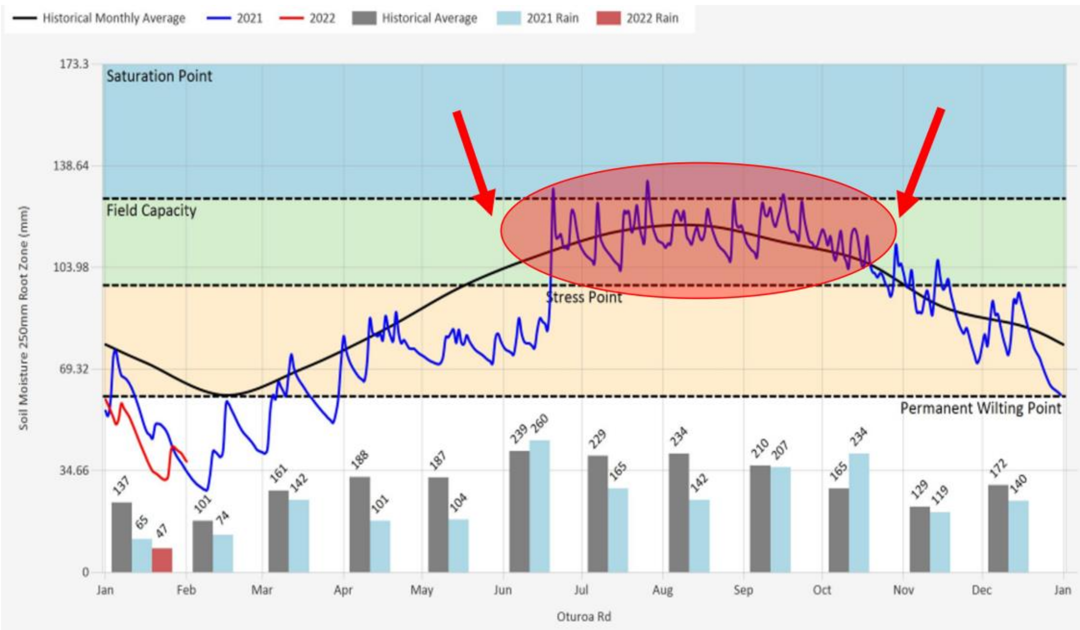

Figure 1. Active nitrate leaching period (red ellipse marking June to October) indicated on plot of soil moisture data (lines), Oturoa Road, Rotorua. Total monthly rainfall data (in mm) represented by bars (Bay of Plenty Regional Council (BOPRC), 2022).

In contrast, the other three key contaminants (phosphorus, sediment and pathogens) are mainly transported off-farm to waterways during episodic overland events i.e., relatively brief periods of time during sustained high intensity (usually >10 mm/hr for >1 hr) rainfall events (Table 1).

Table 1. Key agricultural contaminants, their pathways, temporal status, and delivery time

Contaminant		Transport pathway	State of active transport	Time delay* - point of loss to destination water body
1	**Nitrogen**	**Leaching** to aquifers	**Seasonal** ≈ 45% of year	Delayed e.g. Waiteti aquifer age ≈ **75 years**
2	**Phosphorus**	**Runoff** during storms	**Episodic** flows ≈ 0.1 to 0.5% of the year	Unrestrained ≈ **1 to 7 hours** Detainment Bund ^{PS120} treated ≈ **3 days** (if any)
3	**Sediment**			
4	**Pathogens**			

*Duration figures and assumptions based on the rainfall and soil characteristics of the Upper Oturoa area, Rotorua, Bay of Plenty, New Zealand

Detainment Bund ^{PS120} mitigation performance

Utilising especially built Detainment Bunds as a means of intercepting and treating storm water surface run-off, was the subject of a 'proof of concept' study in 2013, a masters research thesis by Clarke (2013). The Clarke study clearly demonstrated that given adequate ponding capacity (m^3) relative to catchment sizes (ha) i.e. a ponding volume to catchment size ratio of ≥ 120:1, the Detainment Bund ^{PS120} (DB) concept is successful for mitigating storm water loads and retains contaminants (phosphorus and sediment) on farm. However due to the limitations of instruments and time, the Clarke study, although clearly a successful 'proof of concept' finding, could not quantify how well the Detainment Bund concept worked.

Research into the performance of individual DBs was initiated by a farmer governance group (the Phosphorus Mitigation Project Inc.) in 2016 which raised funds, directed, and enabled PhD research which measured the effectiveness of DBs in reducing contaminant loads. This applied research showed that Detainment Bunds^{PS120} serving pastoral catchments of up to 50 ha on free draining soil types, can reduce the contaminate load in runoff by an average of 57 % (Levine, 2020). Performance of DBs for *E. coli* reduction has commenced (Stott, 2022) and is ongoing.

To differentiate these specially constructed bunds from other types of storm water interception structures, e.g. variously sized sediment traps, the Phosphorus Mitigation Project Inc has named its performance researched Detainment Bunds^{PS120} with the inclusion of a suffix, ^{PS120}, where the P, S and 120 respectively represent validated performance for phosphorus and sediment mitigation given a minimum ponding capacity threshold of ≥ 120 cubic metres m^3 per hectare.

Opportunities and benefits with runoff interception

As three of the four key New Zealand agricultural contaminants affecting water quality (Table 1) move off the farm mainly during very brief episodic rainstorm runoff events, it's important to consider the water quality benefits of on-farm mitigation effort on treating the contaminant loads during those temporal stormwater runoff events.

The benefits of stormwater interception also extend beyond water quality mitigation (phosphorus and sediment) to human health (*E. coli*), storm peak management (safety), positive effects on down-stream erosion and aquifer recharge. The multiple benefits, including implications for management of climate change effects are listed in the Detainment Bund Guideline (Paterson, 2019a) and copied in Table 2 below.

Table 2. Multiple benefits of DBs and their performance evidence (from Detainment Bund Manual, Paterson, 2019a).

	Issue (cause)	DB benefits	DBs result in	Validated by
1	**Water quality** (phosphorus)	Phosphorus (P), in farm runoff captured in DBs.	Proven 47 % to 68 % reduction of P load in storm water runoff	Completed research PhD: Levine, 2020; MSc: Clarke, 2013.
2	**Water quality** (sediment)	Sediment captured in DBs.	Proven 51 % to 59 % reduction of sediment in storm water run-off	
3	**Human health** (*E. coli*)[3]	Possible pathogens captured, reducing risk to potable water and downstream "swimmability".	Validation trials 2020-2022. Likely similar to P and sediment results in 1. and 2. above i.e. > 50 % reduction in *E. coli*. Result pending.	Known association of *Escherichia coli* (*E.coli*) with sediment in runoff. Stott 2022. Current PMP Inc. applied research project. (Completion date: 2024).
4	**Erosion** (sediment)	Moderation of erosive peak flows by DBs.	Limiting downstream erosion (banks, head wall gullying).	100+ historic Detainment Dams (DDs) built 1980-2000 in the BOP region.
5	**Flood** (safety)	Moderation of peak flows by DBs during floods.	Limiting injury and loss of life from flooding induced road accidents.	DB works funded for peak flow risk reduction to public roads, road safety.
6	**Flood** (destruction)	Less downstream infrastructure maintenance cost.	Limiting damage to housing, bridges, culverts, roads, pasture and water supply.	As above. Existing DB works funded for this purpose. Umurua catchment Rotorua.
7	**Aquifer depletion** (groundwater)	'Aquifer recharge' through run-off residency in DB ponding area.	Proven 43 % to 63 % infiltration through up to 72-hour DB ponding residency time.	Completed research PhD: Levine, 2020; MSc: Clarke, 2013.

The opportunities for Detainment Bund installation are dependent on finding appropriate locations where adequate ponding relative to catchment size (the 120:1 threshold) can be achieved. This search process for specific DB sites requires skilled GIS analysis supported by high resolution LiDAR and is described in the Detainment Bund Guideline (Paterson, 2019a). Broader non-specific landscape suitability for DB application can be assessed using a GIS based model, the DB Applicability Model (DBAM) (Paterson, 2019b). This model assesses the percentage of any given farming landscape that can be treated by DBs with ± 6 % accuracy.

Depending on topography, farmed landscapes are variously suitable for DB installation, with DB applicability rates ranging 50-90 % of farm productive areas. Given the average 57.5 % efficacy rate of DBs, this will result in 29 to 52 % less contaminant loads than would have otherwise flowed into local waterways during regular storm events.

Risks related to intercepting storm water

While there are multiple benefits with the potential widespread uptake of relatively small DBs by the farming community, these need to be balanced against the assessment of potential risk when compared to dams as shown in Table 3. Key components of risk for storm water holding structures are simply; their height, volume and the size of the upstream catchments where runoff is generated.

Table 3. Inherent risk of scaling: dams versus DBs (adapted from Paterson, 2019a)

Differentiating features – Dams versus DBs		
Decreasing Risk of Failure →		
Large Dam (classifiable)	**Small Dam**	**Detainment Bund**
Permanent water holding	Permanent water holding	Temporary ponding
4m or more height	Less than 4m high	Generally, ≤ 2.5m high
20,000m³ or more volume	Less than 20,000 m³ volume	1,000m³ to 5,000m³ volume
Requires a local authority Resource Consent and a Building Permit to construct	Permitted Activity – with variable Local authority 'conditions' across NZ. No regulatory differentiation of detainment bunds from small dams	

Large dam regulation

Large dam regulation has recently been subject to consultation and review (MBIE, 2019). Owners of dams will be required to assess the Potential Impact Classification (PIC) status of their dam i.e. whether or not the large dam regulation applies to them. New regulations on dam safety are expected to be made in the first half of 2022 (Building Performance, 2021). "The intent is that small dams will be excluded from the regulations. This includes small dams, irrigation races, stock drinking ponds and weir" (Building Performance, 2021).

Risk levels for damage ranging from minimal to catastrophic are proposed in the review of 'classifiable' Large Dams (MBIE, 2019) as indicated in Table 4. This is based on the likelihood of harm to downstream populations and damage to property and the environment. The threshold for this level of caution is whether or not the structure is 'classifiable', that is, at or above 4 m in height and 20,000 m^3 in volume or where a dam may be less than 4 m high but at or above 30,000 m^3 in volume. Measurement of dams is defined in section 133B of the Building Act 2004, available on the New Zealand Legislation website.

Table 4. Determination of Potential Impact Classification, adapted from MBIE, 2019.

Large dam failure consequences: damage categories					
Damage level	Residences destroyed	Critical infrastructure		Natural environment	Community Recovery
		Damage	Rebuild time		
Catastrophic	>50 house destroyed, 2 or more lives lost	Extensive destruction to several infrastructures	>1 year	Extensive damage	Many years
Major	4 to 49 destroyed + some damaged, likely a life lost	Extensive destruction to >1 infrastructure	≤1 year	Costly restoration	Some years
Moderate	1 to 3 destroyed + some damaged	Extensive destruction to 1 infrastructure	Up to 3 months	Significant damage	Months
Minimal	Minor damage	Minor damage to infrastructure	Up to 1 week	Short-term damage	Days/weeks

Detainment Bund[PS120] – a perspective of risk

Good earthworks practice during DB construction and particularly laying down earth with a high standard of compaction, including quality control monitoring, is fundamental for minimising the risk of failure. Detail of construction practice risks is not included in this paper. We focus on the inherent risks of proposed DB locations rather than the earthworks process.

Over 30 DBs have been built in the Rotorua Lakes catchments and while the maximum catchment can be up to 42 ha, the average catchment size of these structures is less than 20 ha with average ponding volumes less than 2,500 m³. Extensive DB placement scenarios have been undertaken in preparation for whole catchment adoption (Paterson, 2020). This catchment scoping process, for DB applicability, uses GIS with high resolution LIDAR. Scoping data for two Lake Rotorua sub-catchments, the Umurua and the Hauraki (Table 5), shows that DB average catchment sizes differ from one catchment to another, 13 ha and 25 ha respectively. Similarly, the average DB volumes differ between the two catchments (1,745 m³ and 3,317 m³ respectively).

This difference is due to the topographies of the two catchments. The Umurua is steeper making it the more challenging catchment for DB fitting (65 % applicability compared to 77 % in the Hauraki catchment) resulting in less opportunities for larger DBs with bigger ponding volumes.

Table 5. Average catchment size and ponding volumes for two sub-catchments of Lake Rotorua: the Umurua and Hauraki catchments following scenario analysis of DB applicability (Paterson, 2020).

Sub-Catchments surveyed for DBs	Total DB sites proposed	% of total catchment Treatable by DBs	Average DB catchment	Av. DB height	Av DB Water depth	Av. DB Volume
Umurua 2,641 ha	135	65%	12.7 ha	2.0m	0.66m	1,745m³
Hauraki 1,261 ha	38	77%	25.4 ha	2.0m	0.66m	3,317m³

These DB mitigation ponding volumes (averaging approximately 2,500 m³) are minor when compared to the threshold volume for regulated large dams (20,000 m³) i.e. DBs average approximately 1/8th of the size of the smallest 'large dam'. As the majority of dam failure risk to people and property is arguably strongly related to water inundation from massive volumes released suddenly by dam failure, it follows that minor volumes (from any DB failure) correspondingly pose greatly diminished risk of inundation harm to people and property.

Regulatory barriers to Detainment Bund^PS120 uptake

As mitigating DBs are a relatively new advent they postdate current rule provisions. In all Regional Council plans across New Zealand DBs fall by default into the small dam building area of regulation. DB construction is a permitted activity however between regions, height and volume limits vary as well as other conditions that apply to that permitted activity. The regulation pertaining to small dams is summarised in a report prepared by NIWA for DairyNZ and MBIE titled '*Regulatory barriers to uptake of farm-scale diffuse pollution mitigation measures'* (Milne, 2020). An excerpt from this NIWA report, Table 6 below, shows the variability of regulation pertaining to small dams, and to DBs by default, in local authority plans throughout New Zealand.

Some regions set limits to dam heights well below the certifiable large dam limit of 4 m but most are set at 3 m (Milne, 2020). In three of the 16 regional authority plans, dam volume limits are at 5,000 m³ but the other 13 regions appear to have no limit other than the certifiable large dam limit of 20,000 m³. None of the Regional Plans appear to have construction site risk assessments as an integral component of their rule provisions.

Table 6. Summary of the range of 'Permitted Activity' conditions in NZ Regional Council plans (copied from Table 3-5, Milne (2020)).

Region	Conditions to be satisfied: Not located in a specified high value watercourse	Max. upstream catchment area	Maximum water depth and volume of impounded water [b]	Spillway flood passage design	Residual flow to be maintained out of dam at all times	No reduction in flood flow conveyance	Sediment discharge criteria apply	No conspicuous change in colour or clarity of receiving waters after reasonable mixing	No contaminant discharge other than sediment	Maintain fish passage upstream and downstream
Northland	✓			1% AEP	✓			✓	✓	✓
Auckland [a]			4 m	1% AEP		✓		✓		✓
Waikato	✓	100 ha	3 m & 20,000 m^3	"maximum probable flood"			✓			
Bay of Plenty	✓ [b]		1.5 m & 5,000 m^3 [c]	100-yr flood	✓					✓
Gisborne	✓	5 ha	3 m & 20,000 m^3			✓		✓	✓	✓
Hawke's Bay		50 ha	4 m & 20,000 m^3	"storm events"	✓	✓				✓
Taranaki	✓	25 ha	3 m (max. height)	"flood flows"				✓		✓
Manawatu-Whanganui	✓	50 ha	3 m [d]	200-yr flood	✓	✓	✓	✓	✓	✓
Wellington		20 ha	3 m [d] & 20,000 m^3	20-yr flood	✓					
Tasman	✓	<20 ha	< 3 m & 5,000 m^3	2% AEP			✓	✓		✓
Nelson				No permitted activity rule identified for the construction of an instream dam						
Marlborough				No permitted activity rule identified for the construction of an instream dam						
West Coast	✓	50 ha	3 m & 20,000 m^3	"maximum probable flood"						✓
Canterbury	✓		3 m & 5,000 m^3		✓					✓
Otago	✓	50 ha	3 m & 20,000 m^3							
Southland	✓	500 ha		✓ (narrative)					✓	✓

[a] Applies to an existing instream dam only (i.e., no permitted activity rule exists to construct a new instream dam). [b] Also, the mean annual daily flow of the river or stream must be ≤ 150 L/s. [c] Applies to dams within rivers; multiple permitted activity rules exist and different criteria apply to dams within artificial watercourses. [d] Check the relevant regional plan for details on how measurements are made.

In the current BOPRC Regional Natural Resources Plan (BOPRC, 2018) a further condition of dam rule WQ R16 (not shown in the Table 6 summary) is that the permitted activity requires the engagement of a Chartered Professional Engineer. As there is no preliminary risk assessment of DB sites, all sites are assumed to be dangerous and the level of engineer input and its cost is unrestrained by a needs assessment. Consequently, in the Bay of Plenty the preliminary cost for engineering oversight alone has ranged from \$10,000 to \$30,000 which exceeds the actual earthworks construction costs in some cases. In effect the BOPRC regulations more than double the overall DB construction costs compared to other regions of New Zealand.

While we have compelling evidence of the multiple environmental benefits of installing DBs (Section 3 above) and farm owners are generally willing to accommodate DBs in their farming systems, they are also cost conscious and particularly resistant to paying unjustified start-up costs over and above the cost of the actual DB earthworks (multiple farmers, personal communication with the author J. Paterson). There will certainly be no general uptake of mitigating DBs on farms in the Bay of Plenty until the dam rules are reviewed, DBs are differentiated from dams, and DB sites are risk assessed to justify an appropriate level of engineer oversight, if any. Such changes will remove the current regulatory generated cost barrier to farmers wishing to take up installation of environmental mitigation DBs for water quality objectives.

Detainment Bund [PS120] – site specific risk identification

Risk measures inherent with DB sites address two fundamental areas of risk:

- consequences of failure to people and property downstream
- failure of the DB structure itself.

There are ten elements of risk assessed and scored in the risk assessment process as illustrated in Table 7 below; three relate to consequences of DB failure for others downstream and seven focus on the risks with the DB structure itself.

Table 7. Ten measurable elements of risk suitable for risk assessment calculator entry.

1	Distance to boundary	(Flowpath measurement, m)
2	Volume of DB pond	(m^3) Greater volume / Greater risk
3	Infrastructure below	(Flowpath distance, m) e.g. homes within 30m flood width band?
4	Catchment Size (ha)	Bigger the catchment, Bigger the risk
5	DB Height (m)	1 to 3.9m range only - Higher the height, Higher the risk
6	Storage Ratio (m^3 : ha)	120:1 optimal – lower ratios = higher risk
7	Soil Drainage (mm/hr)	Proxy for clay content – construction materials risk
8	Sub Soil/Geology	Suitability of local construction materials
9	Slope (°) downstream	Steeper slopes = greater erosion failure risk
10	Slope (°) upstream	Proxy for 'Time of concentration' – steeper slopes = higher risk

1 - Distance to boundary

The further the DB location is away from the farms boundary, the less risk any failure will cause harm and damage to neighbouring people and property. This element is scored with a range from 1 (low risk, >500 m to boundary) to 10 (high risk, <50 m to boundary)

2 - Volume of DB pond

The smaller the volume contained in the DB, the less risk any failure will cause harm and damage to neighbouring people and property. This element is scored with a range from 1 (low risk, <750 m^3) to 10 (high risk, >15,000 m^3). Note: certifiable large dams are ≥20,000 m^3.

3 - Infrastructure downstream

The greater the flow distance for an escaping surge of water from a failed structure, the more opportunity there is for the surge to be dissipated by the flow path. The distance from the DB to any private and public infrastructure e.g., houses, public roads/bridges) along a 60 m wide outflow corridor is measured and scored from 1 (low risk, >2 km) to 10 (high risk, <100 m).

4 - Catchment Size

The greater a DBs catchment size, the more potential there is for greater volumes of runoff to be generated. Note: most current DBs have less than 42 ha of catchment. This element is scored with a range from 1 (low risk, <10 ha) to 10 (high risk, >75 ha).

5 - DB height

The greater a DBs wall height, the more potential for failure issues. Note: DBs are currently built ≤2.5 m high with the average height around 2 m. The certifiable large dam threshold is ≥4 m. This element is scored with a range from 1 (low risk, <1 m) to 10 (high risk, <4 m).

6 - Storage Ratio (m^3/ha)

The storage ratio is a theorem to measure the adequacy of any structure regardless of catchment size. High storage ratio DBs have more capacity for storm water than low ratio structures. For example, a low ratio structure, say 40 m^3/ha will fill quickly during a storm and regularly need to use its overland emergency spillway i.e., increased stress on the structure. This element is scored with a range from 1 (low risk, >170:1) to 10 (high risk, <50:1).

7 - Soil drainage (mm/hr)

Soils that are free draining generally have a low clay content and low clay content is less favourable as a building material for a bund. A water tight seal of the bund wall requires a high standard of compaction and is harder to achieve with low clay content material. Soil drainage rates are effectively a proxy for clay content. The infiltration rates can be measured on site or, where available. derived from soil maps. This element is scored with a range from 1 (low risk, <5 mm/hr) to 10 (high risk, >40 mm/hr).

8 - Subsoil suitability for DB construction.

Sub-soil borrowed from areas close to the DB footprint is the most common building material. The suitability of this material for compacting into the bund wall is likely known for the DB site from local observations and experience. If in doubt, samples can be taken for lab testing. This element is scored from 1 (low risk, clay subsoil) to 10 (high risk, coarse gravel).

9 - Slope of downstream flow path with provision for incised flow paths

DBs perched on hillsides have greater risk of being subject to headwall erosion undermining the bund wall versus a DB located in the middle of a relatively flat valley floor. Slope (°) is measured over the first 100 m downstream of the bund DB. This element is scored with a range from 1 low risk (<1° slope and not incised) to 10 (>7° slope and incised for 80 m out of 100 m).

10 - Slope upstream

The slope of the catchment valley floor measured from the DB footprint to the furthest extent of the catchment gives an indication of catchment response time during a run-off event or 'time of concentration'. Steep slopes above a DB means runoff will arrive quickly and pose greater threat to the structure. There is also provision to note any known erosion issues related to slope and shift the risk score accordingly. This element is scored with a range from 1 low risk (<1° slope with no erosion issues) to 10 (>12° slope and/or noted mass earth movement issues).

The Detainment Bund Risk Assessment Algorithm (DBRAA)

Given the scores for the ten risk elements for a particular DB site, these are entered into an excel based calculator where the summation of risk scores are automatically filed into one of six risk categories as illustrated in the first column in Table 8. These risk categories range from 'no apparent risk' to 'high risk'. Note that 'high risk' on this scale is less than the 'minimal category' for damage consequences for the 'Large Dam' risk categories illustrated earlier in Table 4. Calibration was undertaken by using seven completed DB structures as controls.

Table 8. The DBRAA calculator's key outputs: where a 'risk score' is assigned a 'category' which corresponds to a 'grade' that describes the appropriate degree of engineer input required. A preliminary indication of the likely oversight costs is included.

Risk Score	Risk Category	Cautions grade and indicative oversight costs	
0 to 29	**No apparent risk**	**Grade 1**	≈ $600
30 to 39	**Less than minor risk**	**Grade 2**	≈ $1,200
40 to 49	**Minor risk**	**Grade 3**	≈ $1,700
50 to 59	**Moderate risk**	**Grade 4**	≈ $5,500
60 to 69	**Moderate to high risk**	**Grade 5**	≈ $8,000
70 to 100	**High risk**	**Grade 6**	≈ $11,000

DBRAA – Screenshot example

A DBRAA output example illustrating the data entry table scores is illustrated in Table 9 below. Note this example is a very small existing DB with a catchment of 7.4 ha and a large DB ponding capacity of 235 m³/ha (the DB minimum threshold is 120 m³/ha). The risk score also reflects that there is a boundary fence nearby and a public road adjacent. This site scores 34 and is delegated to Grade 2: ‘less than minor risk’.

Table 9. Screenshot of DBRAA data entry page with scoring entered from an existing DB.

Pre-construction DB Site Risk Assessment Scoring

Landowner: *Anonymous*

Risk No	Risk Type	Score level: 1 (Low Risk)	2	4	6	8	10 (High Risk)	Score
R1	**Distance to boundary (Flowpath, m)** An infrastructure/safety caution	> 500	250 to 499	150 to 249	100 to 149	50 to 99	0 to 49	4
				4				
R2	**Storage Volume (m³)**	0 to 749	750 to 1,499	1,500 to 2,499	2,500 to 4,999	5,000 to 14,999	> 15,000	4
				4				
R3	**Infrastructure** Distance (m) to downstream infrastructure that is within 30 m of the flowpath centre	> 2000	1,000 to 2,000	500 to 999	200 to 499	100 to 199	< 100	6
					6			
R4	**Catchment Size (ha)**	0 to 9.9	10 to 19.9	20 to 41.9	42 to 59.9	60 to 74.9	> 75	1
		1						
R5	**DB Height (m)** to spillway	0 to .9	1 to 1.4	1.5 to 1.9	2 to 2.5	2.6 to 3.5	3.6 to 3.9	4
				4				
R6	**Storage Ratio (m³ : ha)**	> 170 : 1	130 to 169 : 1	100 to 129 : 1	70 to 99 : 1	50 to 69 : 1	< 50 : 1	1
		1						
R7	**Soil Drainage (mm/hr)** Proxy for clay content	< 5	5 to 9.9	10 to 19.9	20 to 29.9	30 to 40	> 40	4
				4				
R8	**Sub Soil/Geology Suitability for DB cor** Local observation, experience & tests + known compactability	Low risk 1 clay	2 clay loam	'known OK' 3 ignimbrite	4 sandy loam	Volc. ash / sand 5 sand	High risk 6 coarse gravel	4
				4				
R9	**Slope (°) or Incised downstream** Slope down flowpath over 100 m (°), *OR* Incised (m) / 1st 100 m of flowpath	0 to 0.9 Not Incised	1 to 1.9 Not incised	2 to 2.9 Not incised	3 to 4.9 Incised 0 to 29 / 100	5 to 6.9 Incised 30 to 69 / 10(	> 7 ncised 80 to 100 / 100	2
			2					
R10	**Slope (°) upstream** to upper catchment extent + any known erosion issues e.g. mass earth movement	0 to 0.9	1 to 2.4	2.5 to 3.9	4 to 6.9	7 to 12	> 12	4
				4				

Farm Data Entry

Boundary distance (m)			220
Storage Volume (m³)			1,754
Infrastructure (m)			350
Catchment Size (ha)			7.4
DB Height (m)			1.65
Storage Ratio (m³ : ha)			235
Soil Drainage (mm/hr)			15
Geology Suitability low risk (1) to high risk (6)			3
Downstream Slope (°): *Incised or non-incised: choose the greater risk*			
Incised (m / 1st 100 m of flowpath)			
or	Rise (m)	1	
Non-incised	Run (m)	37	1.55
Upstream Slope (°	Rise (m)	32	
	Run (m)	534	3.43

Score: 34 GRADE 2, Less than minor risk

After input of scoring data for a DB site, DBRAA determines an appropriate risk category and suggests appropriate engineer oversight cautions and an indicative cost (Table 10).

Table 10. Screenshot of DBRAA with risk category ‘Grade 2 – Less than minor risks of consequences’ automatically selected and displayed following data entry (Table 9).

Grade 2 - Less than minor risks or consequences

					CPE site visit	Hours	Rate	Est.cost
S4	**CPE engagement**	LMO	1	LMO submits DB construction proposal with preliminary risk grading to selected CPE				
		CPE	2	CPE reviews preliminary Risk Assessment process / arrangement made for site visit with all parties		1	200	$200
S5	**CPE - initial site visit**	CPE, LMO	1	CPE augurs ground and manually checks the risk grading elements for sub-soil/geology suitability	1	2	200	$400
		Landowner	2	Confirmation of preliminary Risk Scoring and Risk Grading (1-6)				

Design and oversight requirements for Grade 2

			Generic design construction actions				
Earthworks preliminary	LMO	1	Provision of; reference to standard Generic Design for proposed DB, generic compaction protocol, pipe, riser and spillway sizing via generic look up table				
		2	Provide DB constructions plan (from 1 above) in format suitable for transfer to land owner and earthworks contractor				
		3	Provide contractor with instructions for compaction method and template for compaction logging				
Earthworks - quality control	LMO	1	Set appropriate seasonal timelines for works to start and finish				
		2	At ground opening undertake Key Trench inspection - Take photos - discuss any issues with CPE				
		3	Pipe installation inspection when installed (not covered) - confirm compaction around pipe - photgraph contractors compaction record log				
		4	File notes, photos with LO property file at BOPRC and cc copy to CPE				
Works completion	LMO and CPE	1	Inspection at works end but before machinery departs from the site - confirm compaction records with scala penetrometer test on centreline of bund	2	3	200	$600
	LMO	2	Post contstruction site review: Protection from stock pugging in place? Grass sward established? Riser installed with drainage hole at correct level?				
		3	Final filing of notes, photos with LO property file at BOPRC and cc copy to CPE				

Note: due to Risk Grade 2, the following are optional; lab testing of materials, armouring at outfall of pipe, armouring overland spillway with geotextile, drainage sleeve around pipe

Grade 2 $1,200

Enquiries for access to this DBRAA Excel based algorithm can be directed to the corresponding author.

Conclusion

Episodic high intensity rainfall runoff events occur for very brief moments of time and it is these brief events where the majority of phosphorus, sediment and *E. coli* leave productive farm pasture and affect downstream water quality. This runoff can be intercepted by Detainment Bunds[PS120] but it is not without risk. Selection and assessment of proposed DB sites is conducted mainly with use of GIS and LiDAR data attributes entered into the DB risk assessment algorithm (DBRAA). DBRAA enables each DB site's footprint, upstream catchment and downstream flow-path characteristics to be precisely assessed, quantified and risk graded. In most situations the multiple benefits of retaining and treating stormwater for water quality objectives and other wider community environmental services will significantly outweigh the risk of bund failure. If DB failure should occur, the consequences to people and property in most cases will likely be minor or un-noticed.

Most Regional Plans do not yet specifically recognise Detainment Bund mitigation and their construction subsequently defaults to small dam regulations. This is generally a permitted activity, however in some regions required conditions are borne from presumed high risk. The requirement of chartered professional engineer design and oversight can result in costs that are out of context with actual risk and inhibitory to farmer uptake at a time when addressing water quality issues is a primary issue for agricultural businesses and communities.

The DB risk assessment algorithm (DBRAA) provides a relative measure of the level of risk at individual DB sites and indicates an appropriate category of engineer advice (if any) that should be undertaken for each site based on that site's particular risk attributes.

Recognition of specific site risks, through use of DBRAA, should result in development of more appropriate permitted activity regulation specific to DBs. This will result in better cost efficiency of DB roll out and enable the majority of farmer funds to be used for the actual implementation of DB earthworks with appropriate attention to risk and the cautions needed to mitigate that risk.

Rule development in future regional plans need to ***enable*** water quality mitigations and differentiate between environmental mitigation structures and dams. DBs are not dams and water residency time in DBs at full capacity/full pressure is 1 to 2 % of the year versus 100 % for a dam. Also, unlike dams, DBs operate with a plug (to control ponding/limit pasture inundation) so can be rapidly de-watered if any issues arise.

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